

COMPOSITION AND COLOR OF MARTIAN SOIL FROM OXIDATION OF METEORITIC MATERIAL

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Overview: The conventional explanations for the formation of ferric oxides on Mars involve weathering under aqueous conditions. Mineralogical evidence, however, does not support extensive, global alteration by liquid water. An alternative method for producing the ferric oxides is based upon oxidation of meteoritic iron either soon after the impact event or over geologic timescales under present martian conditions.

Limited aqueous weathering on Mars: The soil samples analyzed at the Pathfinder landing site have concentrations of iron and magnesium which indicate that they are not derived exclusively from the local rocks [1]. One possible explanation of this finding is that these soils contain a component of weathered basalts [2]. Basaltic rocks are believed to be abundant on Mars and may have been altered through aqueous processes early in martian history. Subsequent redistribution of the weathering products by global aeolian activity *may* explain the composition of the soils at the Pathfinder site.

The problem with this interpretation, however, is the lack of supporting mineralogical evidence for extensive global weathering by liquid water. Data from the Mars Global Surveyor Thermal Emission Spectrometer indicate the presence of unweathered pyroxenes in low albedo regions of the planet [3]. Under a water-rich environment, these minerals would rapidly alter to clay minerals and hematite. Neither of these secondary phases have been detected in association with the pyroxenes. In addition, there is no convincing evidence for the presence of any clay minerals on Mars. The 2.2 to 2.35 micrometer cation-OH modes characteristic of clays are conspicuously absent in reflectance spectra. Furthermore, the atmosphere that would have been necessary to support liquid water at the surface of Mars would have resulted in the formation of extensive carbonate deposits, equivalent to tens of meters in thickness over the entire planet. Yet, none have been detected in spectroscopic searches.

Thus, the addition of *weathered* basalts may not be the best explanation for the chemical composition of the soil at the Pathfinder site.

Exogenic influx: Consider an alternative mechanism for introducing the mafic components to the Pathfinder soils without invoking an aqueous weathering history: Meteoritic influx. Fe, Mg, and S are among

the most abundant rock/soil-forming elements in the solar system, and an exogenic source of chondritic material could easily add the necessary elements to produce the soil composition (see figure 1).

The idea of a meteoritic component in the martian soil is not new. The spectral reflectivity of Mars was matched to oxidized meteoritic material as early as 1970 [4]. Viking in-situ data showed that the composition of the fines is well reproduced by a mixture of CI chondrites and basaltic rock [5]. Estimates suggest that 2% to 29% of the martian soil could be from micrometeorites [6]. Thus, it is reasonable to expect that the influx of meteoritic material could help explain the elemental composition of the soil.

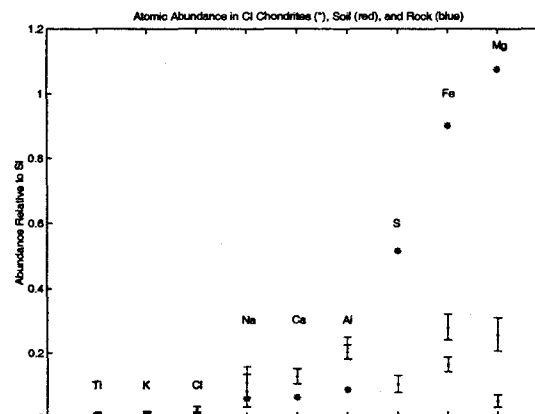


Figure 1: Plot of atomic abundances relative to Si for CI chondrites (*) [7], Pathfinder soil [8], and Pathfinder sulfur free rock [9]. Meteoritic Fe and Mg could fill the gap between the rock and soil compositions.

Oxidation upon impact: The ferric component of the soil and Mars' characteristic color could have been produced during the impact events that introduced the meteoritic material [10]. Partial vaporization of impactors and target material, recondensation in the atmosphere, and precipitation as soil and dust grains was likely an active process during the latter stages of planetary accretion. During these transient high temperature conditions under oxidizing atmospheres, metallic and ferrous iron can be readily converted to the ferric state. Continuing with the premise that abundant liquid water was not available on early Mars, there

would not have been an efficient removal process for these impact-generated grains. Thus, primitive meteoritic debris transported globally by billions of years of aeolian activity could constitute a significant portion of the soil and dust at the martian surface.

This concept of a significant exogenic soil component is consistent with several unique aspects of the martian soil. Recondensation of vaporized rock in a gaseous atmosphere would likely result in extremely small grains, poorly crystalline mineral phases, and particles which are not uniform in composition. These characteristics are all consistent with interpretations of Mars soil data, including magnetic properties investigations suggesting that the magnetic phases on Mars reside in composite particles [11]. In addition, a sub-aerial conversion to ferric iron does not require an intermediate oxyhydroxide phase, for which no clear evidence exists and for which a plausible mechanism for dehydroxylation at the martian surface has not been identified [12].

Oxidation after impact: The subset of meteoritic iron which escapes oxidation during the impact event can be slowly altered to the ferric state under surface conditions similar to present-day Mars. We have shown that electrons can be mobilized within mineral grains by ultraviolet radiation and that capture by gas phase oxygen can remove the electrons from the substrate, forming adsorbed superoxide [13]. The removal of this electron is, by definition, an oxidation process.

Here, we show that ultraviolet radiation under a simulated martian atmosphere is capable of oxidizing metallic iron. A thin-film of Fe (1000 Å) deposited by electron beam sublimation under high vacuum was exposed to UV radiation under a simulated martian atmosphere. Analysis by x-ray photoelectron spectroscopy (XPS) clearly shows the formation of iron oxide after UV treatment (see figure 2). XPS is sensitive to the composition of the uppermost atomic monolayer, while techniques such as x-ray diffraction requiring multiple lattice spacings did not detect the formation of oxide. The need for a *surface* analytical instrument to identify the iron oxide after UV exposures equivalent to approximately 1 martian year indicates that the alteration process is slow under present martian conditions. Exposure over geologic timescales, however, could produce the micrometer-thick layers of oxide necessary to be observable at visible wavelengths.

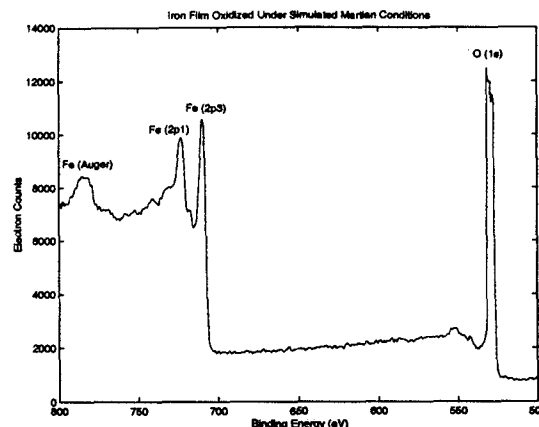


Figure 2: X-ray photoelectron spectra showing an oxide formed on metallic iron under simulated martian conditions. The oxygen signal and the $2p_{3/2}$ binding energy peak of Fe centered at approximately 710.0 eV are indicative of an oxide. This Fe peak occurs at approximately 706.5 eV for unoxidized films for an equivalent depth in the sample.

Conclusion: The chemical composition of the soil and the characteristic color of Mars can be explained by iron introduced to the surface by meteoritic influx. Oxidation to the currently observed ferric state could have occurred during the impact event or after subsequent exposure to the martian environment over geologic timescales.

- References:** [1] Rieder R. et al. (1997) *Science*, 278, 1771-1774. [2] Morris R. V. et al. (2000) *JGR*, 105, 1757-1817. [3] Christensen P. R. et al. (2000) *JGR*, 105, 9609-9621. [4] Gibson E. K. (1970) *Icarus*, 13, 96-99. [5] Clark B. C. and A. K. Baird (1979) *JGR*, 84, 8395-8403. [6] Flynn G. J. and D. S. McKay (1990) *JGR*, 95, 14,497-14,509. [7] Morris R. V. et al. (1995) *JGR*, 100, 5319-5328. [8] Sears D. W. G. and R. T. Dodd (1988) in *Meteorites and the Early Solar System*, Univ. of Arizona Press. [9] McSween H. Y. and K. Keil (2000) *GCA*, 64, 2155-2166. [10] Bell J. F. et al. (2000) *JGR*, 105, 1721-1755. [11] Hviid et al. (1997) *Science*, 278, 1768-1770. [12] Yen et al. (1999) *JGR*, 104, 27,031-27,041. [13] Yen et al. (2000) *Science*, 289, 1909-1912.